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Shimizu

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(54) **INPUT APPARATUS AND CONTROL METHOD FOR INPUT APPARATUS**

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G06F 3/041 (2006.01)
G06F 3/01 (2006.01)

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CPC ***G06F 3/0416*** (2013.01); ***G06F 3/016*** (2013.01); ***G06F 3/0414*** (2013.01)

(58) **Field of Classification Search**
CPC B41J 2/04581; B41J 2/04541; B41J 2/04588
See application file for complete search history.

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(57) **ABSTRACT**

An input apparatus includes: a touch sensor **11**; a piezoelectric element **13**; a piezoelectric element drive unit **15**; a control unit **17** configured to detect a pressure load on the touch sensor **11** based on an output signal of the piezoelectric element **13** and, when the pressure load satisfies a standard to provide a tactile sensation, to control the piezoelectric element drive unit **15** to drive the piezoelectric element **13** such that the tactile sensation is provided to a pressing object; a connection switchover unit **14** configured to selectively connect the piezoelectric element **13** to the control unit **17** or the piezoelectric element drive unit **15**; and a discharge circuit **16** configured to discharge electric charge in the piezoelectric element **13**. When the pressure load satisfies the standard, the control unit **17** controls the connection switchover unit **14** to connect the piezoelectric element **13** to the piezoelectric element drive unit **15** such that the piezoelectric element **13** is driven, and then controls the discharge circuit **16** to discharge the electric charge in the piezoelectric element **13**.

4 Claims, 6 Drawing Sheets

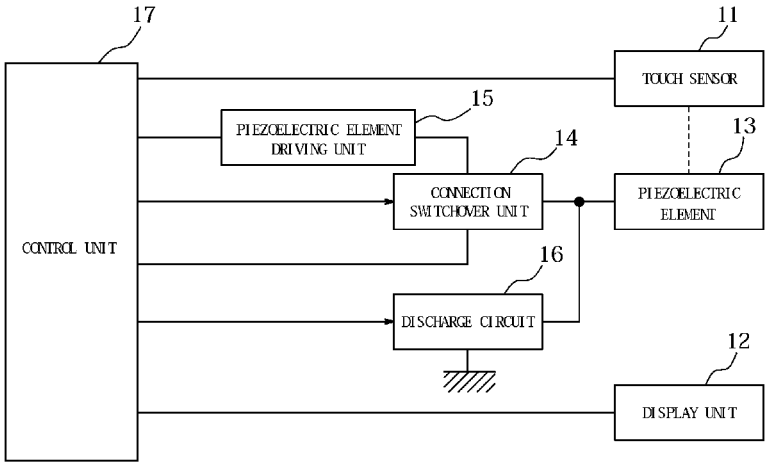

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FIG. 1

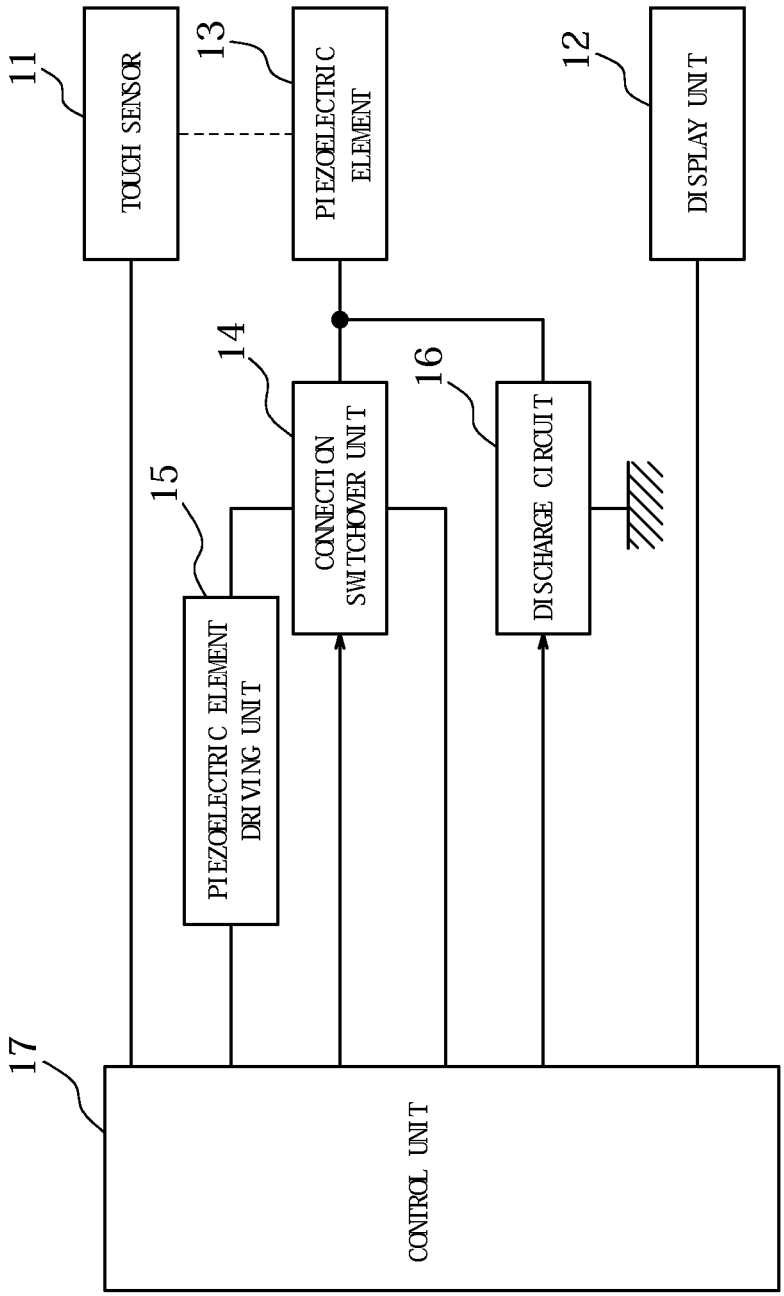

11
TOUCH SENSOR
13
PIEZOELECTRIC ELEMENT
12
DISPLAY UNIT
14
CONNECTION SWITCHOVER UNIT
16
DISCHARGE CIRCUIT
15
PIEZOELECTRIC ELEMENT DRIVING UNIT
17
CONTROL UNIT

FIG. 2

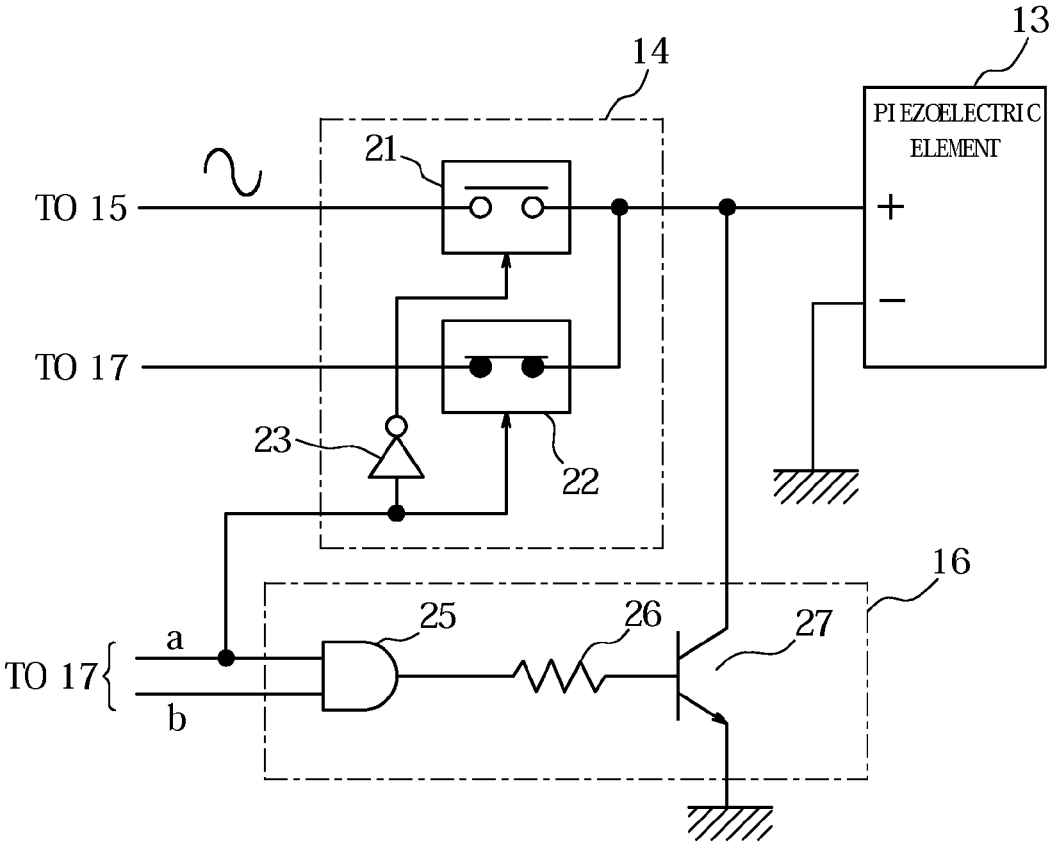

13
14
PIEZOELECTRIC ELEMENT
+
−
21
TO 15
TO 17
23
22
16
25
26
27
TO 17
a
b

FIG. 3

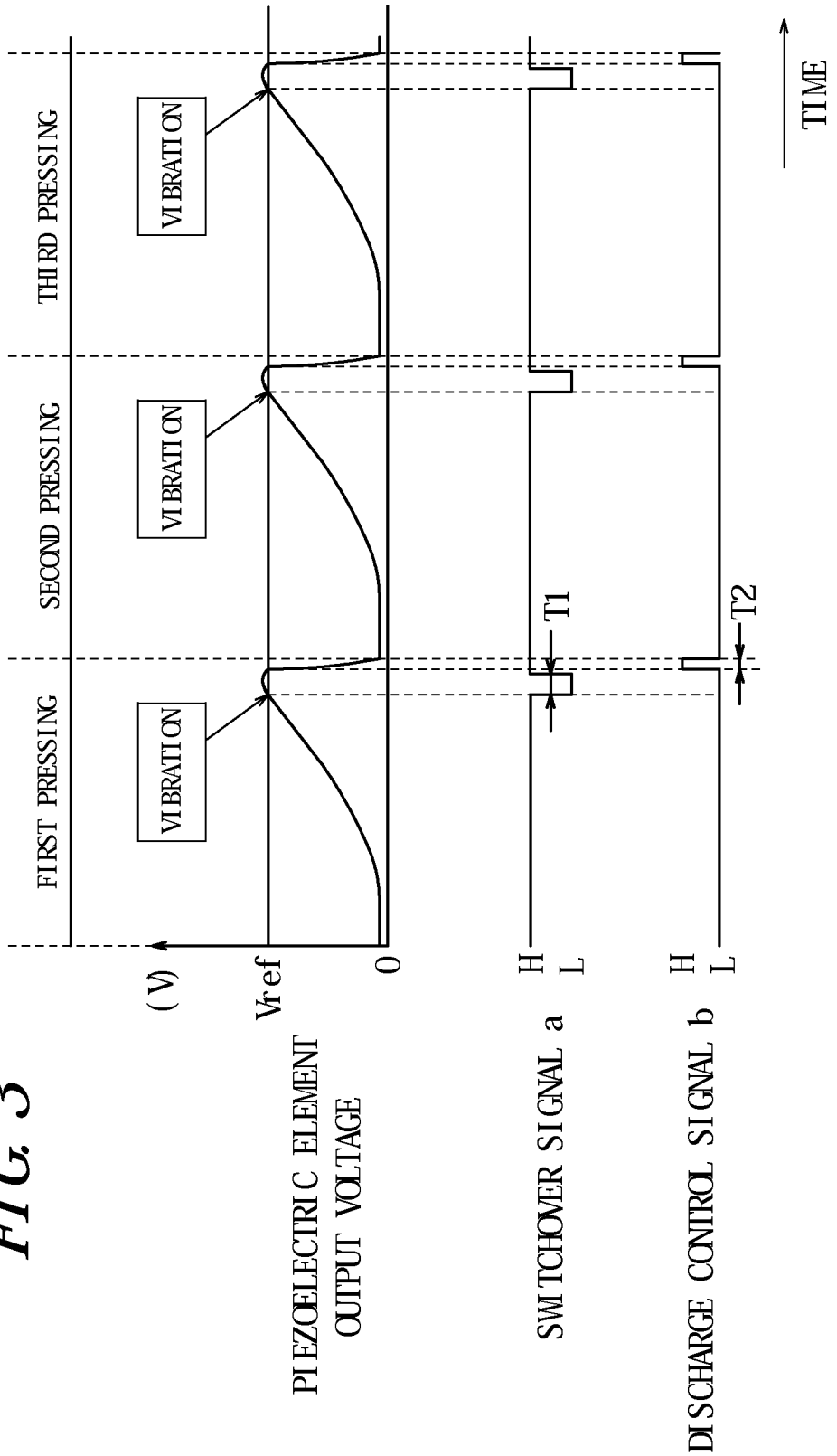

FIRST PRESSING
SECOND PRESSING
THIRD PRESSING
VIBRATION
VIBRATION
VIBRATION
(V)
Vref
0
PIEZOELECTRIC ELEMENT OUTPUT VOLTAGE
H
L
SWITCHOVER SIGNAL a
T1
H
L
DISCHARGE CONTROL SIGNAL b
T2
TIME

FIG. 4

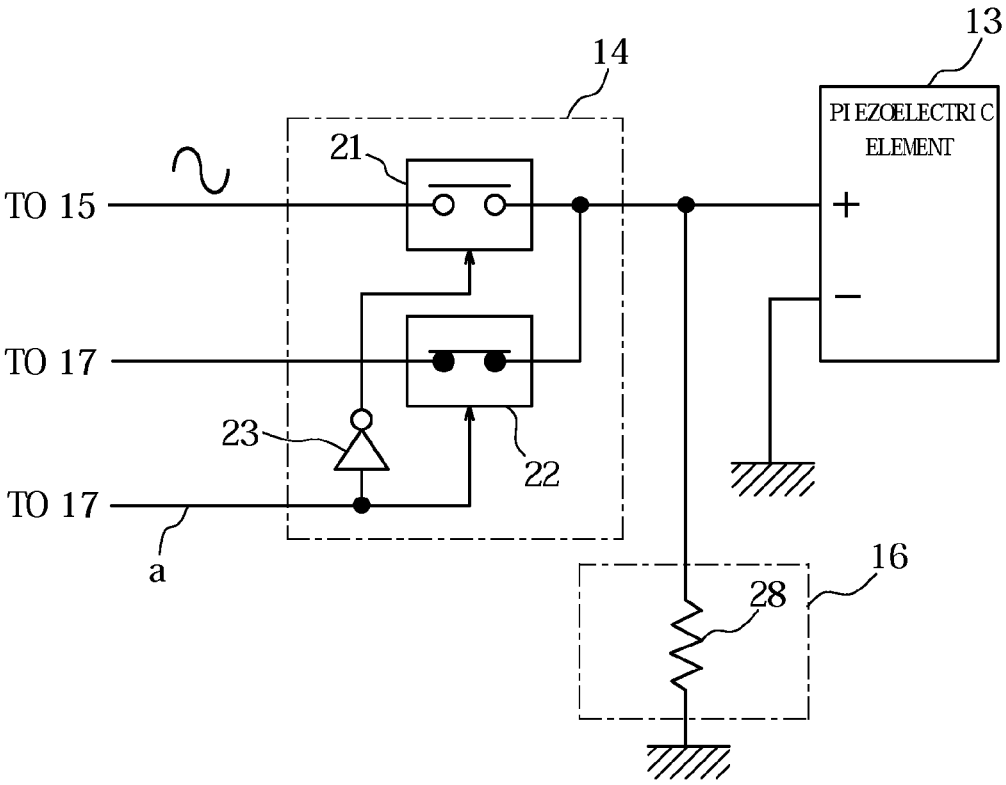
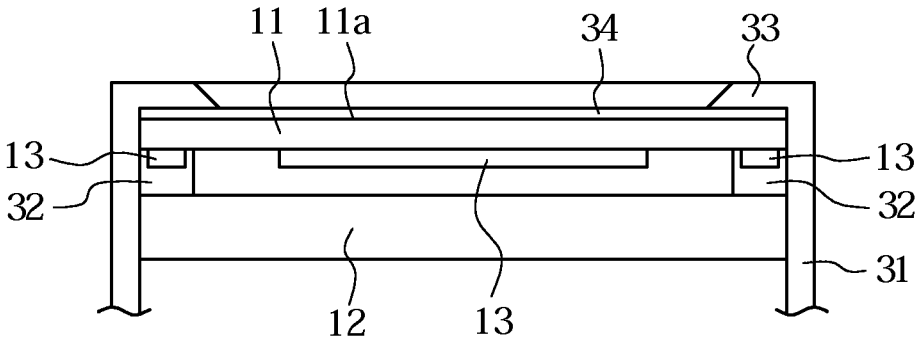


FIG. 5

(a)



(b)

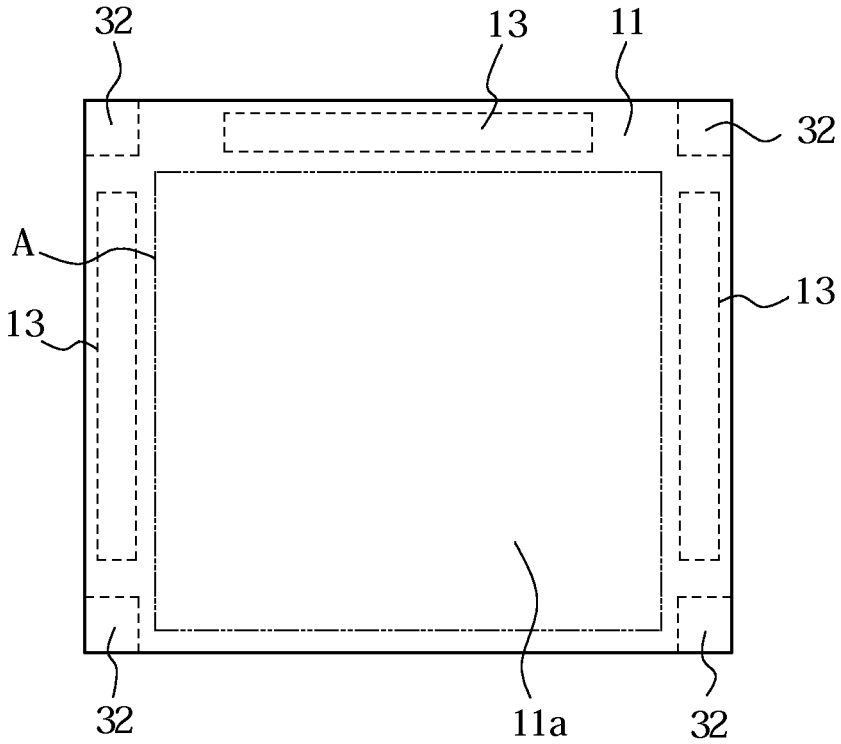
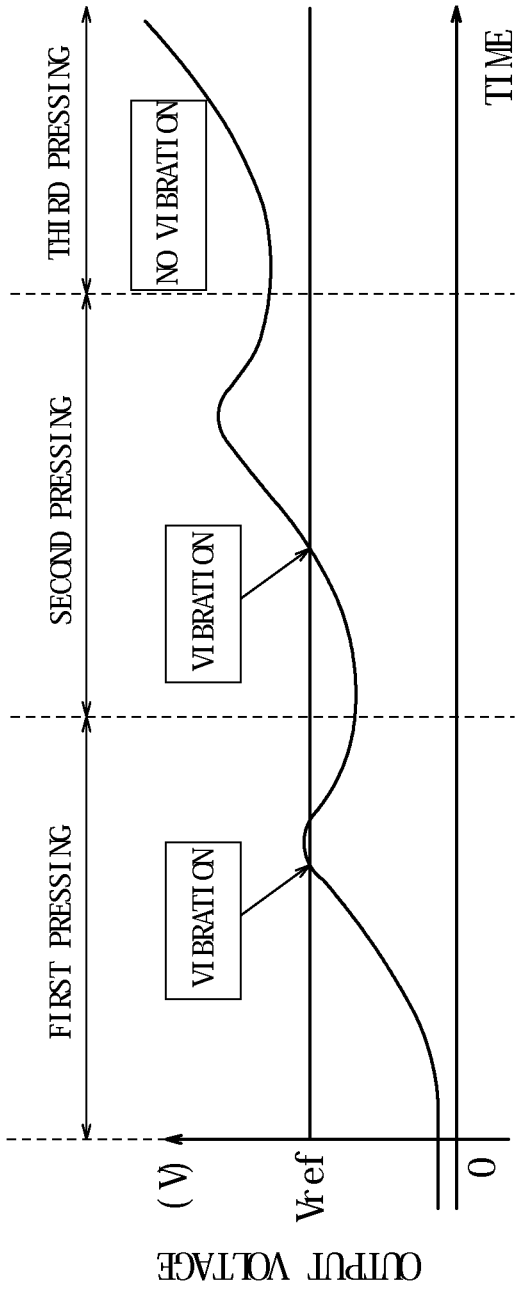


FIG. 6


FIRST PRESSING
SECOND PRESSING
THIRD PRESSING
VIBRATION
VIBRATION
NO VIBRATION
OUTPUT VOLTAGE
(V)
Vref
0
TIME

INPUT APPARATUS AND CONTROL METHOD FOR INPUT APPARATUS

CROSS REFERENCE TO RELATED APPLICATION

This application claims priority to and the benefit of Japanese Patent Application No. 2009-197377 filed on Aug. 27, 2009, the entire contents of which are incorporated herein by reference.

TECHNICAL FIELD

The present invention relates to an input apparatus having a touch sensor and a control method for an input apparatus.

BACKGROUND ART

In recent years, input apparatuses having touch sensors such as touch panels, touch switches or the like are popularly used as input apparatuses such as operation units, switches and the like for receiving input operations by a user in mobile terminals such as mobile phones, information equipments such as calculator, ticket vending machines, home electric appliances such as microwaves, TV sets, lighting equipments, industrial equipments (FA equipments) and the like.

There are known a variety of types of those touch sensors, such as a resistive film type, a capacitive type, an optical type and the like. However, touch sensors of any of these types receive a touch input by a finger or a stylus pen and, unlike push-button switches, the touch sensors themselves are not physically displaced even when being touched.

Since the touch sensors are not physically displaced when touched, an operator cannot obtain feedback to an input even when the touch input is received. As a result, the operator is likely to input erroneously by touching the same spot multiple times, which may be stressful for the operator.

As methods to prevent such erroneous inputs, there are known methods of visually or auditory confirming the input operations by, for example, generating sounds or by changing a display state, such as colors of input objects such as input buttons and the like graphically depicted on a display unit, according to an input area upon reception of the touch input.

However, such auditory feedback may be difficult to be confirmed in a noisy environment and is not applicable when the equipment being used is in a silent mode. In addition, in using such visual feedback, if the input object displayed on the display unit is small, the operator may not be able to confirm the change in the display state, as a view of the input object is blocked by a finger, particularly when the operator is inputting by the finger.

There is also suggested a feedback method relying on neither the auditory- nor visual sensation but instead generating a tactile sensation at operator's fingertip by vibrating the touch sensor when the touch sensor receives an input (for example, see Patent Documents 1, 2).

RELATED ART DOCUMENTS

Patent Documents

Patent Document 1: Japanese Patent Laid-Open No. 2003-288158 Patent Document 2: Japanese Patent Laid-Open No. 2008-130055

SUMMARY OF INVENTION

Technical Problem

The techniques disclosed in the above Patent Documents 1 and 2, however, merely vibrate the touch sensor when the touch sensor receives an input. Therefore, especially in using the input apparatus having the button switch such as a mechanical push-button switch (push-type button switch) graphically depicted on the touch sensor having a low threshold to receive the input, a tactile sensation is provided when the finger or the like lightly contacts (touches) the touch sensor. It may trigger erroneous operations by responding to an unintentional motion (touch) before the operator pushes and inflict a feeling of strangeness on the operator upon the unintentional motion (touch). Here, the threshold for the touch sensor to receive a touch input is a threshold at which the touch sensor responds. For a touch sensor of the resistive film type, the threshold is a threshold of pressure at which an upper conductive film is contacted to a lower conductive film and, for a touch sensor of the capacitive type, the threshold is a threshold for detection of an electric signal by contact.

In order to clear such a disadvantage, the applicant has developed an input apparatus which detects a pressure load on a touch face of the touch sensor and, when the pressure load detected reaches a predetermined threshold to provide the tactile sensation, vibrates the touch face of the touch sensor such that the tactile sensation is provided to a pressing object such as the finger or the like.

According to this input apparatus, the tactile sensation is provided when the operator pushes the touch face and the pressure load of the push reaches the predetermined threshold. As a result, it is possible to allow the operator to perceive reception of an input while reliably preventing erroneous operations triggered by an unintentional touch described above and the feeling of strangeness.

Incidentally, the input apparatus needs a load sensor to detect the pressure load on the touch sensor and an actuator to vibrate the touch sensor in addition to basic components such as the touch sensor and a control unit. As a result, the number of components and cost are increased, as well as a size of the apparatus to retain necessary space for the components.

In order to reduce cost and the size of the apparatus, the applicant has developed an apparatus which utilizes direct piezoelectric effect and converse piezoelectric effect of a piezoelectric element serving dual function as the load sensor to detect the pressure load on the touch face of the touch sensor and the actuator to vibrate the touch face.

As a result of various experiments and studies, however, the inventor observed that, in using the piezoelectric element for dual function as the load sensor and as the actuator, there is a need for an improvement as follows. For example, when the touch sensor is continuously pressed in the same manner as a repetitive input (repetitive tap) to a push-button key, the piezoelectric element is bent at each pressing. As a result, as illustrated in FIG. **6**, before electrical charge generated in the piezoelectric element due to bend of the piezoelectric element is completely discharged, the electric charge is generated in the piezoelectric element in next pressing, and thereby the output voltage of the piezoelectric element is increased.

Accordingly, if the piezoelectric element is controlled to function as the actuator to vibrate the touch face when the output voltage, or the pressure load of the piezoelectric element, increases and exceeds a predetermined threshold

Vref, the output voltage exceeding the threshold Vref is not detected in some cases depending on the setting of threshold Vref. For example, although the output voltage of the piezoelectric element exceeding the threshold Vref only in first pressing or the output voltages only in first and second pressing are detected (in a case of FIG. **6**), the output voltages in pressings thereafter stay over the threshold Vref, and thus it is not detected that the output voltages exceed the threshold Vref.

In the case of FIG. **6**, as a result, the piezoelectric element are controlled to function as the actuator to vibrate the touch face in response to only the first and second pressing, but not in response to pressing thereafter. Accordingly, since the tactile sensation is provided to the operator only in response to the first and second pressing but not provided in response to pressing thereafter in continuous pressing, the operator may have the feeling of strangeness.

Hence, an object of the present invention, in consideration of such a condition, is to provide an input apparatus, which reduces cost and its size and appropriately provides the tactile sensation to the operator without inflicting the feeling of strangeness on the operator in operating the touch sensor.

Solution to Problem

In order to achieve the above object, an input apparatus according to a first aspect of the present invention includes:

a touch sensor configured to detect a touch input;

a piezoelectric element mounted on the touch sensor;

a piezoelectric element drive unit configured to drive the piezoelectric element;

a control unit configured to detect a pressure load on a touch face of the touch sensor based on an output signal of the piezoelectric element and to control the piezoelectric element drive unit, when the pressure load detected satisfies a standard to provide a tactile sensation, to drive the piezoelectric element such that the tactile sensation is provided to an object pressing the touch face;

a connection switchover unit configured to selectively connect the piezoelectric element to the control unit or the piezoelectric element drive unit; and

a discharge circuit configured to discharge electric charge accumulated in the piezoelectric element, wherein

the control unit, when the pressure load detected based on the output signal of the piezoelectric element input via the connection switchover unit satisfies the standard, controls the connection switchover unit to connect the piezoelectric element to the piezoelectric element drive unit such that the piezoelectric element is driven by the piezoelectric element drive unit, and then

the control unit controls the discharge circuit to discharge the electric charge accumulated in the piezoelectric element.

A second aspect of the present invention is the input apparatus according to the first aspect, wherein

the discharge circuit has a switching element connected between the piezoelectric element and ground, and

the control unit, after vibration of the piezoelectric element by the piezoelectric element drive unit, conducts the switching element for a predetermined period such that the electric charge accumulated in the piezoelectric element is discharged.

A third aspect of the present invention is the input apparatus according to the first aspect, wherein

the discharge circuit has a resistor element connected between the piezoelectric element and ground.

In addition, in order to achieve the above object, a control method of an input apparatus according to a fourth aspect of the present invention including

a touch sensor configured to detect a touch input,

a piezoelectric element mounted on the touch sensor,

a piezoelectric element drive unit configured to drive the piezoelectric element,

a connection switchover unit configured to selectively connect the piezoelectric element to the piezoelectric element drive unit, and

a discharge circuit configured to discharge electric charge accumulated in the piezoelectric element, including the steps of:

detecting a pressure load on a touch face of the touch sensor based on an output signal of the piezoelectric element and controlling the connection switchover unit, when the pressure load detected satisfies a standard to provide a tactile sensation, to connect the piezoelectric element to the piezoelectric element drive unit and controlling the piezoelectric element drive unit to drive the piezoelectric element such that the tactile sensation is provided to an object pressing the touch face; and then

controlling the discharge circuit to discharge the electric charge accumulated in the piezoelectric element.

Effect of the Invention

The input apparatus according to the present invention, utilizing direct piezoelectric effect and converse piezoelectric effect of the piezoelectric element, uses the piezoelectric element as a load sensor to detect the pressure load on the touch face of the touch sensor and as an actuator to vibrate the touch face. It is thus possible to reduce the number of components and the cost as well as to save space for the components for downsizing the apparatus. In addition, after drive of the piezoelectric element, while the piezoelectric element is electrically disconnected from the piezoelectric element drive unit, the discharge circuit discharges electric charge (residual electric charge) accumulated in the piezoelectric element. Therefore, it is possible to prevent continuous accumulation of the electric charge in the piezoelectric element is prevented and the tactile sensation is reliably provide in a continuous input as well without inflicting a feeling of strangeness on an operator.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a functional block diagram illustrating a schematic configuration of an input apparatus according to a first embodiment of the present invention;

FIG. **2** is a circuit diagram illustrating an example of a configuration of a connection switchover unit and a discharge circuit illustrated in FIG. **1**;

FIG. **3** is a timing chart illustrating a schematic operation of the input apparatus illustrated in FIG. **1**;

FIG. **4** is a circuit configuration diagram of a main section of an input apparatus according to a second embodiment of the present invention;

FIG. **5** illustrates a cross-sectional view of a main section and a plane view of the main section which are illustrating an exemplary housing structure of the input apparatus according to the present invention; and

FIG. **6** is a diagram of a change in electric charge accumulated in a piezoelectric element illustrating a problem to be solved by the present invention.

DESCRIPTION OF EMBODIMENTS

Embodiments of the present invention will be described with reference to the accompanying drawings.

First Embodiment

FIG. **1** is a functional block diagram illustrating a schematic configuration of an input apparatus according to a first embodiment of the present invention. This input apparatus has a touch sensor **11**, a display unit **12**, a piezoelectric element **13**, a connection switchover unit **14**, a piezoelectric element drive unit **15**, a discharge circuit **16**, and a control unit **17** to control an operation of each unit.

The touch sensor **11** is connected to the control unit **17** and, under control of the control unit **17**, detects a touch input to a touch face of the touch sensor **11** by a pressing object, such as a finger and the like, and provides the control unit **17** with position information of a touch position. The touch sensor **11** may be of a known type, such as a resistive film type, a capacitive type, an optical type and the like, and disposed on the display unit **12**.

The display unit **12** is connected to the control unit **17** and, under control of the control unit **17**, displays an input object of an input button and the like such as a push-button switch (push-type button switch). The display unit **12** may be constituted by, for example, a liquid crystal display panel, an organic EL display panel and the like. The touch input to the input object displayed on the display unit **12** is detected by the control unit **17** based on the position information output from the touch sensor **11**.

The piezoelectric element **13** is mounted on the touch sensor **11** and designed to be bent (strained) under pressure on the touch face of the touch sensor **11**. The piezoelectric element **13** is connected to the connection switchover unit **14** and selectively connected to the control unit **17** or the piezoelectric element drive unit **15** via the connection switchover unit **14**.

The connection switchover unit **14** may include a switch circuit and the like as described below and, under control of the control unit **17**, selectively connects the piezoelectric element **13** to the control unit **17** or the piezoelectric element drive unit **15**. The piezoelectric element drive unit **15** may include a power amplifier and the like and outputs a predetermined drive signal to vibrate the piezoelectric element **13** under control of the control unit **17**.

While the piezoelectric element **13** is connected to the control unit **17** via the connection switchover unit **14**, an output signal of the piezoelectric element **13**, that is, a voltage of electric charge generated by pressure on the touch face of the touch sensor **11** is supplied to the control unit **17**. In addition, while the piezoelectric element **13** is connected to the piezoelectric element drive unit **15** via the connection switchover unit **14**, the drive signal of the piezoelectric element drive unit **15** is supplied to the piezoelectric element **13** to drive the piezoelectric element **13**. Thereby, the touch sensor **11** is vibrated and provides a tactile sensation to the pressing object pressing the touch face.

The discharge circuit **16** may include a switching element connected to the piezoelectric element **13** as describe below and, under control of the control unit **17**, discharges the electric charge (residual electric charge) accumulated in the piezoelectric element **13**.

The control unit **17** may be, for example, a CPU and the like and controls an operation of each unit based on the position information from the touch sensor **11**, display information for the display unit **12**, the output signal of the piezoelectric element **13** and the like.

FIG. **2** is a circuit diagram illustrating an example of a configuration of the connection switchover unit **14** and the discharge circuit **16** illustrated in FIG. **1**. The connection switchover unit **14** includes two switch circuits **21**, **22**, which may be semiconductor relays and the like, and an inverter **23**. Each of the switch circuits **21**, **22** has an ON/OFF contact point. The ON/OFF contact point of the switch circuit **21** is connected between a positive electrode terminal of the piezoelectric element **13** and an output terminal (not illustrated) of the piezoelectric element drive unit **15**. The ON/Off contact point of the switch circuit **22** is connected between the positive electrode terminal of the piezoelectric element **13** and an analogue/digital conversion input terminal (not illustrated) of the control unit **17**.

The ON/OFF contact point of the switch circuit **21** is turned ON/OFF by a switch changeover signal a output from the control unit **17** through the inverter **23**. The ON/OFF contact point of the switch circuit **22** is turned ON/OFF by the switch changeover signal a set forth above. Accordingly, when one of the contact points of the switch circuits **21**, **22** is ON, the other is OFF.

The discharge circuit **16** has an AND (logical conjunction) circuit **25**, a resistor **26**, and a switching transistor **27** for discharge. A discharge control signal b output from the control unit **17** and the switch changeover signal a set forth above are input to the AND circuit **25**, and an output from the AND circuit **25** is supplied to a base of the switching transistor **27** via the resistor **26**. The positive electrode terminal of the piezoelectric element **13** is connected to ground via a collector-emitter pathway of the switching transistor **27**.

FIG. **3** is a timing chart illustrating a schematic operation of the input apparatus according to the present embodiment. FIG. **3** illustrates the switch changeover signal a and the discharge control signal b, which are output from the control unit **17**, and the output signal (voltage) of the piezoelectric element **13** in a continuous input (repetitive tap) by continuously pressing the touch face of the touch sensor **11**. The control unit **17** ordinarily sets the switch changeover signal a at a high (H) level and the discharge control signal b at a low (L) level. Thereby, the piezoelectric element **13** is connected to the control unit **17** by turning the switch circuit **21** of the switchover control unit **14** OFF and the switch circuit **22** ON. In addition, the discharge circuit **16** sets the output of the AND circuit **25** at the level L and turns the switching transistor **27** OFF.

In this state, the control unit **17** monitors an output of the touch sensor **11** and the output signal (voltage) of the piezoelectric element **13**. When detecting that the position information from the touch sensor **11** indicates that an input is performed to the input object displayed on the display unit **12** and the output voltage of the piezoelectric element **13** has reached a threshold Vref corresponding to a standard load to provide a tactile sensation (for example, 1 N), the control unit **17** sets the switch changeover signal a at the level L. Thereby, the control unit **17** connects the piezoelectric element **13** to the piezoelectric element drive unit **15** by turning the switch circuit **21** of the switchover control unit **14** ON and the switch circuit **22** OFF.

In this state, then, the control unit **17** controls the piezoelectric element drive unit **15** to output the predetermined drive signal to drive the piezoelectric element **13**. Thereby, the touch panel **11** is vibrated such that the tactile sensation is provided to the pressing object pressing the touch face. In addition, the control unit **17** performs predetermined opera-

tions for the input object in the display unit **12** such as, for example, changing a display state, displaying a character corresponding to the input object in a predetermined display area, executing and processing application corresponding to the input object, and the like.

Then, when the piezoelectric element drive unit **15** finishes driving the piezoelectric element **13**, the control unit **17** sets the switch changeover signal a at the level H and turns the switch circuit **21** and the switch circuit **22** back to OFF and ON, respectively. Thereby, the piezoelectric element **13** is disconnected from the piezoelectric drive unit **15** and connected to the control unit **17**. Here, a period T_1 to maintain the switch changeover signal a at the level L may be fixedly set (for example, approximately 5 ms) including a drive time of the piezoelectric element **13** or automatically set according to the drive time to drive the piezoelectric element **13** by the drive signal corresponding to the tactile sensation to provide.

Then, while the switch changeover signal a is at the level H, the control unit **17** sets the discharge control signal b at the level H for a predetermined discharge period T_2. Thereby, an output of the AND circuit **25** of the discharge circuit **16** is set at the level H for the predetermined discharge period T_2 and the switching transistor **27** is conducted such that the residual electric charge accumulated in the piezoelectric element **13** is discharged via the switching transistor **27**.

Here, a period from a point when the switch changeover signal a is switched from the level L to the level H, that is, a point when the period T_1 to maintain the switch changeover signal a at the level L ends to a point when the discharge control signal b is set at the level H, that is, a point when the predetermined discharge time T_2 starts, is set up by taking in consideration a response time of the switch circuit **21** of the connection switchover unit **14**, that is, a time for the ON/OFF contact point of the switch circuit **21** certainly changes from an ON state to an OFF state. In addition, the predetermined discharge period T_2 to maintain the discharge control signal b at the level H is appropriately set (for example, approximately 1 ms) based on the threshold Vref, the drive signal for the piezoelectric element **13**, intervals between sequential pressing in a continuous input and the like, such that the residual electric charge accumulated in the piezoelectric element **13** is substantially completely discharged and the output voltage of the piezoelectric element **13** becomes almost 0 V.

After discharge of the piezoelectric element **13**, the control unit **17** monitors the output signal of the piezoelectric element **13** and controls each of the units based on the output signal as described above.

According to the present embodiment, as described above, the input apparatus, utilizing direct piezoelectric effect and converse piezoelectric effect of the piezoelectric element **13**, uses the piezoelectric element **13** as a load sensor to detect the pressure load on the touch face of the touch sensor **11** and as an actuator to vibrate the touch face. Thereby, the same component is shared for a plurality of functions. It is thus possible to reduce the number of components and cost as well as to save space for the components for downsizing the apparatus.

In addition, after the piezoelectric element **13** is driven and provides the tactile sensation, the discharge circuit **16** discharges the residual electrical charge accumulated in the piezoelectric element **13** while the piezoelectric element **13** is electrically disconnected from the piezoelectric element drive unit **15**. Thereby, it is possible to prevent continuous accumulation of the electrical charge in the piezoelectric element **13**, which, as illustrated in FIG. **3**, enables the tactile sensation to be reliably provided at each of sequential pressing in the continuous input without inflicting a feeling of strangeness on the operator. Moreover, since the piezoelectric element drive unit **15** is disconnected from the piezoelectric element **13** when the piezoelectric element **13** is discharged, an output terminal such as a power amplifier and the like constituting the piezoelectric element drive unit **15** is not connected to ground. Therefore, the piezoelectric element drive unit **15** is not adversely affected.

Second Embodiment

FIG. **4** is a circuit configuration diagram of a main section of an input apparatus according to a second embodiment of the present invention. This input apparatus has the same configuration as that in FIG. **2**, except for configuring a discharge circuit **16** by a resistor element **28** connected between the positive electrode terminal of the piezoelectric element **13** and ground in the circuit diagram illustrated FIG. **2**. Therefore, the same components as those illustrated in FIG. **2** are provided with the same reference signs and descriptions thereof are omitted.

According to the input apparatus of the present embodiment, in order to discharge the residual electric charge in the piezoelectric element **13** through the resistor element **28**, the piezoelectric element **13** is connected to the piezoelectric element drive unit **15** for the period T_1 illustrated in FIG. **3** when the piezoelectric element drive unit **15** drives the piezoelectric element **13**. Thereby, the piezoelectric element **13** starts discharging the residual electric charge immediately after being driven by the piezoelectric element drive unit **15**.

According to the input apparatus of the present embodiment, therefore, it is possible to obtain the same effect as the first embodiment. In addition, since the discharge circuit **16** is more simply structured in comparison to that of the first embodiment and there is no need for the discharge control signal b, the configuration and control become simpler, allowing for further reduction in the cost.

Next, an exemplary housing structure of the input apparatus according to the first and second embodiments set forth above will be described with reference to FIG. **5**.

FIG. **5** illustrates an exemplary housing structure of the touch sensor **11**, the display unit **12** and the piezoelectric element **13** illustrated in FIG. **1**; FIG. **5**(*a*) is a cross-sectional view of a main section, and FIG. **5**(*b*) is a plane view of the main section. The display unit **12** is contained in a housing **31**. The touch sensor **11** is disposed on the display unit **12** via insulators **32** made of elastic members. According to the present embodiment, the touch sensor **11** is disposed on the display unit **12** via the insulators **32** arranged at four corners outside a display area A of the display unit **12** illustrated by a chain double-dashed line in FIG. **5**(*b*).

The housing **31** is provided with an upper cover **33** covering a surface area of the touch sensor **11** outside the display area of the display unit **12**. For a dust-proof purpose, an insulator **34** made of elastic member is arranged between the upper cover **33** and the touch sensor **11**.

The touch sensor **11** illustrated in FIG. **5** may have, for example, a surface member having a touch face **11***a* and constituted by a transparent film or the glass, and a rear face member constituted by the glass or acryl. The touch sensor **11** is designed such that, when the touch face **11***a* is pressed down via the insulator **34**, a pushed part and an entire touch sensor **11** are bent (strained) slightly in accordance with the pressure.

The piezoelectric element **13** is provided on the rear face of the touch sensor **11** at a position covered by the upper cover **33** close to a periphery on one side or each of a plurality of sides, for example, three sides. These three piezoelectric elements **13** detect the pressure load on the touch face **11***a* of the touch sensor **11** and vibrate the touch sensor **11** such that the tactile sensation is provided to the pressing object pressing the touch face **11***a*. It is to be noted that the housing **31**, the upper cover **33** and the insulator **34** illustrated in FIG. **5**(*a*) are omitted in FIG. **5**(*b*).

Here, the three piezoelectric elements **13** are connected to the piezoelectric element drive unit **15** via the connection switchover unit **14** and driven by a common drive signal or individual drive signals. In addition, the three piezoelectric elements **13** supply the outputs in parallel to the control unit **17** via the connection switchover unit **14**. Further, the discharge circuit is provided for each of the three piezoelectric elements **13**.

Then, the control unit **17** calculates the pressure load based on the output signals from the three piezoelectric elements **13**. Preferably, results of calculation of the pressure loads are approximately the same when the operator feels nearly the same pressure sensation (hard feeling, soft feeling and the like) at each position on the touch face **11***a*. To that end, the control unit **17** calculates the pressure load based on, for example, an average value of the outputs of the three piezoelectric elements, a weighted additional value and the like. Additionally, it is preferable to apply individual drive signals to the three piezoelectric elements **13** such that the operator obtains nearly the same pressure sensation and nearly the same tactile sensation (feeling of texture and the like) at each position on the touch face **11***a*. Therefore, the piezoelectric element drive unit **15** appropriately changes amplitude, a phase and the like of each of the drive signals in accordance with a position and a location on the touch face **11***a* such that an approximately identical feeling of a combination of the pressure sensation and the tactile sensation is obtained.

Next, the standard of the pressure load to provide the tactile sensation in each of the above embodiments and the drive signal to drive the piezoelectric element **13** will be described.

The standard of the pressure load to provide the tactile sensation may be appropriately set in accordance with a load characteristic of an intended push-button switch in pressing. For example, the standard is set to be equal to a load at which the touch sensor **11** responds to the touch input (synchronizing a timing to provide the tactile sensation with a timing of response to the touch input by the touch sensor **11**) or to be higher than the load at which the touch sensor **11** responds to the touch input (setting the timing to provide the tactile sensation later than the timing of response to the touch input by the touch sensor **11**). For example, when the input apparatus according to the present embodiment is applied to a mobile terminal, it is preferable to set the standard equal to or higher than the load at which the touch sensor **11** responds to the touch input (setting the timing to provide the tactile sensation later than the timing of response to the touch input by the touch sensor **11**). Preferably, the standard is set by users as desired, such that an elder user may set it heavier (slower), whereas a user who often writes messages may set it lighter (quicker).

In addition, the drive signal to drive the piezoelectric element **13** by the piezoelectric element drive unit **15** may be appropriately determined based on the tactile sensation to provide. For example, in order to provide a click sensation "Cli", which is obtained when pressing the push-button switch employed by the mobile terminal, the piezoelectric element drive unit **15** drives the piezoelectric element **13** as follows. Upon application of the pressure load satisfying the standard set forth above, the drive signal, for example, a sine wave with a constant frequency of, for example, 100 Hz to 200 Hz, preferably 170 Hz, for 1 period is applied to the piezoelectric element **13** such that the touch face of the touch sensor **11** is vibrated by approximately 15 μm while the pressure load satisfying the standard is applied thereto. Thereby, it is possible to allow the operator to recognize that an input operation is completed, by providing a realistic click sensation to the operator through the pressing object (pressing means) pressing the touch face of the touch sensor **11**. Similarly, in order to provide another click sensation "Click", which is a sensation harder than the click sensation "Cli", the piezoelectric element drive unit **15** applies the drive signal, for example, a sine wave or a square wave with a frequency of, for example, approximately 200 Hz to 500 Hz, for 1 period to the piezoelectric element **13**.

In order to provide the tactile sensation different from the click sensation such as, for example, a soft tactile sensation such as a "throbbing" sensation and a "jelly-like" sensation, the drive signal, for example, a sine wave with a frequency of approximately 200 Hz to 500 Hz, for two or three periods is applied. Alternatively, in order to provide a "vibrating" sensation, the drive signal, for example, a sine wave with a frequency of approximately 200 Hz to 500 Hz, for four or more periods is applied.

Preferably, information on the drive signals to provide those various tactile sensations is stored in a memory unit (not illustrated) such that the user appropriately set the drive signal to provide a desired tactile sensation. It is also preferable, based on the drive signal set, to automatically set the period T_1 illustrated in FIG. **3** in which the switch changeover signal a is maintained at the level L.

As described above, the control unit **17** does not drive the piezoelectric element **13** until the load applied to the touch sensor **11** calculated based on the output of the piezoelectric element **13** satisfies the standard to provide the tactile sensation (for example, 1 N). Thereby, a tactile sensation of the operator is stimulated. Then, when the load satisfies the standard, the control unit **17** controls the piezoelectric element drive unit **15** to drive the piezoelectric element **13** with the predetermined drive signal such that the touch face **11***a* is vibrated to stimulate the tactile sensation. Thereby, the tactile sensation is provided to the operator such that the operator recognizes that the input operation is completed. Accordingly, even if the button switch such as the push-button switch (push-type button switch) is graphically depicted on the touch sensor, the operator performs the input operation with the touch sensor **11** feeling the realistic click sensation similar to that obtained when operating the push-button switch. Thus, the operator may not have the feeling of strangeness. Moreover, since the operator carries out the input operation in conjunction with perception to "have pressed" the touch sensor **11**, it prevents erroneous inputs caused by mere tapping.

In addition, when the standard of the pressure load to provide the tactile sensation is set higher than the load at which the touch sensor **11** responds to the touch input (setting the timing to provide the tactile sensation later than the timing of response to the touch input by the touch sensor **11**), the control unit **17** determines an input position according to a touch operation to the touch face **11***a* and changes the display state of the input object at a corresponding portion of the display unit **12**. Then, when the pressure load on the touch face **11***a* detected based on the output from the

piezoelectric element **13** satisfies the standard to provide the tactile sensation, the control unit **17** drives the piezoelectric element **13** to provide the tactile sensation and also execute a predetermined operation (for example, execution and processing of a program corresponding to the object) by confirming the input position. In this case, the operator confirms that the input object is selected, by seeing a change of the display state of the input object displayed on the display unit **12**. Moreover, since the click sensation is provided to the operator upon pressing the touch face **11***a*, the operator recognizes that the input object selected is determined (executed). Thereby, erroneous inputs by a so-called wandering finger are prevented.

In providing the click sensation of the push-button switch, it is also possible to provide the same click sensation as that described above in releasing (in this case, release sensation) by driving the piezoelectric element **13** with the drive signal, the same as that in pressing, when the pressure load fails to satisfy the predetermined standard. It is to be appreciated that the drive signal for providing the release sensation does not necessarily need to be the same as that for the click sensation.

In this case, the residual electric charge of the piezoelectric element **13** is discharged through the discharge circuit **16** after providing the release sensation in releasing, without discharging the residual electric charge in the piezoelectric element **13** after providing the click sensation in pressing. Thereby, it is possible to provide a more realistic click sensation, such as the click sensation "Cli" in pressing and a click sensation "Ck" in releasing. The tactile sensations "Cli", "Ck", "Click", the "throbbing" sensation, the "jelly-like" sensation and the "vibrating" sensation set forth in the present specification are sensations obtained by the operator described in Japanese. Examples of the drive signals to provide actual tactile sensations are set forth above.

Here, although the standard of the load to provide the release sensation may be set to be the same as the standard to provide the click sensation in pressing set forth above, it is preferable to set the standard of the load to provide the release sensation to be 50-80% lower than that to provide the click sensation in pressing. Thereby, timings to provide the tactile sensations are synchronized with timings of sequential inputs when the same position (input object) is repeatedly input (tapped), providing the realistic click sensation without the feeling of strangeness. That is, setting the standard of the load to provide the tactile sensation in releasing to be smaller than that in pressing enables to prevent the feeling of strangeness. In addition, setting the standard of the load to provide the tactile sensation in releasing to be approximately 50% or more of that in pressing contributes to a significant improvement in operability in the repetitive input. Moreover, setting the standard of the load to provide the tactile sensation in releasing to be approximately 80% or less of that in pressing enables to deal with a faint load change in a holding state in the repetitive input.

It is to be understood that the present invention is not limited to the embodiments set forth above and various changes may be implemented within the spirit of the present invention. For example, the switch circuits **21**, **22** in FIG. **2** may include a single switch circuit having two contact points. In addition, the switching transistor **27** of the discharge circuit **16** illustrated in FIG. **2** may include a semiconductor relay and the like. Further, the piezoelectric element **13** may have a known configuration such as monomorph, unimorph, bimorph and a laminated type, based on a size, vibration amplitude and the like of the touch sensor **11**.

The present invention is effectively applicable to the input apparatus in which the touch sensor serves as a touch switch for ON/OFF operations. In addition, the input apparatus according to the present invention drives the piezoelectric element when the pressure load detected based on the output of the piezoelectric element satisfies the standard to provide the tactile sensation. Here, "when the pressure load detected based on the output of the piezoelectric element satisfies the standard to provide the tactile sensation" may include either "when the pressure load detected reaches a standard value for providing the tactile sensation", "when the pressure load detected exceeds the standard value for providing the tactile sensation", or "when the standard value to provide the tactile sensation is detected based on the output of the piezoelectric element".

REFERENCE SIGNS LIST

11 touch sensor
11*a* touch face
12 display unit
13 piezoelectric element
14 connection switchover unit
15 piezoelectric element drive unit
16 discharge circuit
17 control unit
31 housing
32 insulator
33 upper cover
34 insulator

The invention claimed is:

1. An input apparatus comprising:
a touch sensor configured to detect a touch input;
a piezoelectric element mounted on the touch sensor;
a piezoelectric element drive unit configured to drive the piezoelectric element;
a control unit configured to detect a pressure load on a touch face of the touch sensor based on an output signal of the piezoelectric element and to control the piezoelectric element drive unit, when the pressure load detected satisfies a standard to provide a tactile sensation, to drive the piezoelectric element such that the tactile sensation is provided to an object pressing the touch face;
a connection switchover unit configured to selectively connect the piezoelectric element to the control unit or the piezoelectric element drive unit; and
a discharge circuit connected between the piezoelectric element and the connection switchover unit, and configured to discharge electric charge accumulated in the piezoelectric element, wherein
the control unit, when the pressure load detected based on the output signal of the piezoelectric element input via the connection switchover unit satisfies the standard, controls the connection switchover unit to connect the piezoelectric element to the piezoelectric element drive unit such that the piezoelectric element is driven by the piezoelectric element drive unit, and then
the control unit controls the discharge circuit to discharge the electric charge accumulated in the piezoelectric element by controlling the connection switchover unit to connect the piezoelectric element to the control unit.

2. The input apparatus according to claim 1, wherein the discharge circuit has a switching element connected between the piezoelectric element and ground, and the control unit, after vibration of the piezoelectric element by the piezoelectric element drive unit, conducts the switching element for a predetermined period such that the electric charge accumulated in the piezoelectric element is discharged.

3. The input apparatus according to claim 1, wherein the discharge circuit has a resistor element connected between the piezoelectric element and ground.

4. A control method of an input apparatus including a touch sensor configured to detect a touch input, a piezoelectric element mounted on the touch sensor, a piezoelectric element drive unit configured to drive the piezoelectric element, a connection switchover unit configured to selectively connect the piezoelectric element to the piezoelectric element drive unit, a discharge circuit connected between the piezoelectric element and the connection switchover unit, and configured to discharge electric charge accumulated in the piezoelectric element, and a control unit, the method comprising the steps of:

detecting a pressure load on a touch face of the touch sensor based on an output signal of the piezoelectric element and controlling the connection switchover unit, when the pressure load detected satisfies a standard to provide a tactile sensation, to connect the piezoelectric element to the piezoelectric element drive unit and controlling the piezoelectric element drive unit to drive the piezoelectric element such that the tactile sensation is provided to an object pressing the touch face; and then controlling the discharge circuit to discharge the electric charge accumulated in the piezoelectric element by controlling the connection switchover unit to connect the piezoelectric element to the control unit.

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